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CATION EXCHANGE CAPACITY OF SOME TROPICAL SOILS OF PUERTO RICO

J. A. BONNET, M. A. LUGO LÓPEZ AND F. ABRUÑA[1]

INTRODUCTION

Cation exchange capacity is the capacity that a soil has to hold cations in readily replaceable forms. Plant nutrients in this form are considered to be readily available to crops. The fact that these cations are fixed by the soil, though in a replaceable form, reduces their losses due to rainfall leaching. In general, it may be said that the higher the total exchange capacity a soil has, the higher its inherent fertility. But a soil with a high value may have unfavorable physical conditions that would limit crop production.

Fundamental knowledge about the nature of the soil exchange complex that is responsible for this exchange capacity is of importance. Three groups of clay minerals are known to constitute the soil complex: Kaolin, hydrous mica or illite, and montmorillonite. One of them may be dominant. The kaolin group has the lowest exchange capacity and possesses favorable physical properties such as good drainage, good aeration, and good structure. The montmorillonite group has the highest exchange capacity and possesses unfavorable physical properties. The characteristics of the illite or hydrous mica group fall between those of the other two. Jeffries, et al. (4)[2] have brought to light new data for the best understanding of the clay minerals of some soils of Puerto Rico.

No data have been published yet concerning the total cation exchange capacity of soils in Puerto Rico, except for exchangeable bases reported in the Soil Survey of Puerto Rico for only nine soil types. Very little has been published from other tropical regions. This paper presents data on the total cation exchange capacity and exchangeable bases of a number of important soil types and groups from Puerto Rico.

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The authors wish to express their appreciation to Dr. F. Ramírez Silva, former Assistant Chemist, Soils Department, for determining some of the total exchange-capacity data reported.

[2] Numerals in parentheses refer to Literature Cited, p. 56.

SOIL SAMPLING AND METHODS

Eighty-one soil samples were collected from one or two depths of the A horizon for 51 soil types in Puerto Rico representing 47 soil series. The soils were classified into 13 great soil groups, according to Roberts (7): Rendzina, Wiesenboden, Reddish Brown, Reddish Chestnut, Reddish Prairie, Gray Brown Podzolic, Red and Yellow Podzolic, Reddish Brown Lateritic, Yellowish Brown Lateritic, Ground Water Laterite, Laterite, Lithosols, and Alluvial.

The total cation exchange capacity was determined by one of the following two methods:

(a) Ten to twenty grams of 20- or 100-mesh soil, depending on its total exchange capacity, were placed in a 100-ml. Truog soil tube and shaken 5 times with 50 ml. of normal calcium chloride solution. The extract was centrifuged and the supernatant liquid discarded. The excess of calcium chloride was washed off with water, followed with 80-percent alcohol, and the supernatant liquid was discarded after centrifuging. The total exchangeable calcium was extracted with normal ammonium acetate solution kept at pH 6.8, and after centrifuging, the extracting solution was evaporated to dryness. The residue was taken up with 10 ml. of hydrochloric acid, diluted with water to a volume of 300 ml., and the calcium precipitated as oxalate and determined volumetrically to calculate the total cation exchange capacity.

(b) Twenty grams of 20-mesh soil were placed over an absorbent c.p. cotton pad in a carbon-filter funnel and leached with 400 ml. of neutral normal ammonium acetate solution. The excess of ammonium was washed off with 400 ml. or more of c.p. ethyl alcohol. The exchangeable ammonium was displaced with a 10-percent solution of sodium chloride containing 0.005 normal hydrochloric acid, the extract was made up to a volume of 500 ml. from which a 200-ml. aliquot, corresponding to 8 gm. of soil, was distilled by adding magnesium oxide. The distillate was collected in standard acid, and the excess of acid titrated with standard alkali. The total exchange capacity, expressed as milliequivalents per 100 gm. of soil, is equal to the milliliters of standard acid used, times normality of the acid, times the factor 12.5.

Exchangeable bases were determined in some soils. Those free of calcium carbonate were leached with a normal ammonium acetate solution kept at pH 6.8; the alcoholic-salt solution recommended by Magistad and Burgess was used for calcareous soils (5). Standard volumetric methods were followed for determining the exchangeable calcium and magnesium; exchangeable sodium was determined by the uranyl acetate method and exchangeable potassium by the cobaltinitrite method.

PRESENTATION OF DATA

The soils were grouped according to the degree of profile development and further subdivided by great soil groups. The total exchange capacities for soil types in the zonal and intrazonal soil groups are reported in table 4 and for azonal soils in table 5, and the minimum and maximum values and their differences in tables 1 and 2, respectively. Exchangeable calcium,

TABLE 1.—*Minimum and maximum values for total exchange capacity in some zonal and intrazonal soil groups of Puerto Rico*

Soil group	Number of samples	Milliequivalents per 100 gm. of dry soil		
		Minimum value	Maximum value	Difference
Rendzina	1	63.5	63.5	—
Wiesenboden	2	36.0	43.2	7.2
Reddish Brown	1	22.6	22.6	—
Reddish Chestnut	4	21.0	41.6	20.6
Reddish Prairie	8	12.0	31.2	19.2
Gray Brown Podzolic	9	5.2	51.6	46.4
Red and Yellow Podzolic	11	8.7	34.1	25.4
Reddish Brown Lateritic	9	5.2	24.0	19.2
Yellowish Brown Lateritic	2	7.7	7.7	—
Ground Water Laterite	2	7.1	1.2	5.9
Laterite	2	2.1	3.2	.9

TABLE 2.—*Minimum and maximum values for total exchange capacity in some azonal soil groups of Puerto Rico*

Soil group	Number of samples	Milliequivalents per 100 gm. of dry soil		
		Minimum value	Maximum value	Difference
Lithosols	8	8.2	40.0	31.8
Alluvial	11	7.7	60.3	52.6

magnesium, potassium and sodium for some soil types and groups of Puerto Rico are reported in table 3.

DISCUSSION

The highest value obtained for total exchange capacity was 63.5 m.e. per 100 gm. of soil for Soller clay, a Rendzina, and the lowest was 2.1 m.e. for Nipe clay, a Laterite (tables 1, 2, 4). In most of the soil groups there is a wide difference between the minimum and maximum values for total exchange capacity varying from 5.9 m.e. in the Ground Water Laterite, to 7.2 in the Wiesenboden, to 20.6 in the Reddish Chestnut, to 19.2 in the

TABLE 3.—*Exchangeable bases for some soil types of Puerto Rico*[1]

Soil type	Soil group	Depth (inches)	Milliequivalents per 100 gm. of dry soil				
			Ca	Mg	K	Na	Total exchangeable bases
Coloso clay	Alluvial	0–12	12.97	1.10	0.92	0.52	15.51
Do.	do.	12–24	11.18	.94	1.08	.36	13.56
Do.	do.	0–12	9.27	.66	.76	.38	11.07
Do.	do.	12–24	7.99	.57	.90	.27	9.73
Do.	do.	0–12	18.08	3.20	.26	.74	22.28
Do.	do.	12–30	14.79	2.89	.17	.82	18.67
Coloso silty clay	do.	0–12	9.03	.41	1.94	.35	11.73
Do.	do.	12–24	8.87	.73	2.73	.45	12.78
Do.	do.	0–12	6.45	.25	1.61	.26	8.57
Do.	do.	12–24	6.34	.44	2.18	.33	9.29
Piñones clay	Wiesenboden	0–12	10.81	.72	.94	.28	12.75
Do.	do.	12–24	10.52	1.05	.84	.37	12.78
San Antón clay loam	Alluvial	0–30	21.60	.15	.50	1.40	23.65
Aguirre clay	do.	0–12	35.10	.14	1.06	3.80	40.10
Do.	do.	0–12	27.40	.31	.62	9.00	37.33
Do.	do.	12–36	24.00	.15	.79	9.50	34.44
Do.	do.	0–12	48.10	.15	.16	11.00	60.41
Do.	do.	0–12	48.80	.27	.59	8.30	57.96
Catalina clay	Reddish Brown Lateritic	0–12	3.40	1.52	.19	—	5.11
Santa Clara clay	Chernozem	0–5	22.01	.90	.16	.74	23.81
Do.	do.	5–17	20.87	1.51	.19	.82	23.39
Ponceña clay	do.	12–16	33.73	1.63	.23	.44	36 03
Santa Isabel silty clay	Reddish Chestnut	6–12	24.01	1.93	.16	1.85	27.95
Santa Isabel clay	do.	0–12	30.00	.16	.43	2.50	33.09
Fe clay	do.	10–22	24.73	2.23	.28	.52	27.76
Paso Seco loam	Reddish Prairie	16–28	17.37	2.23	.17	.37	20.14
Mabí clay	do.	0–6	17.37	3.32	.24	.74	21.67
Do.	do.	6–16	14.01	6.33	.23	1.33	21.90
Coto clay	Yellowish Brown Lateritic	0–7	4.07	.90	.26	.62	5.85
Do.	do.	7–17	.57	.48	.12	.64	1.81

[1] The data given for the Santa Clara clay and other soils down to the Coto clay, except Santa Isable clay, were taken from Roberts (7). The data for Catalina clay were taken from Bonnet (1).

Reddish Prairie and Reddish Brown Lateritic, to 25.4 in the Red and Yellow Podzolic, and to 46.4 in the Gray Brown Podzolic (table 1). The difference for the Lithosols and Alluvial soils (table 2) were 31.8 and 52.6 m.e., respectively. Weathering had been active in the podzolic and more

TABLE 4.—*Total exchange capacity of some soil types*[1] *in some zonal and intrazonal soil groups of Puerto Rico*

Soil type	Soil group	Milliequivalents per 100 gm. of dry soil
Soller clay	Rendzina	63.5
Guánica clay	Wiesenboden	36.0
Do.	do.	43.2
Jácana clay	Reddish Brown	22.6
Fraternidad clay	Reddish Chestnut	21.0
Do.	do.	32.8
Santa Isabel clay	do.	22.0
Do.	do.	41.6
Mabí clay	Reddish Prairie	31.2
Do.	do.	13.3
Do.	do.	18.8
Paso seco silty clay	do.	20.1
Paso seco loam	do.	13.0
Amelia clay	do.	29.4
Llave loam	do.	12.0
Machete loam	do.	14.3
Plata clay	Gray Brown Podzolic	35.7
Ciales clay loam	do.	17.0
Do.	do.	11.8
Utuado loam	do.	10.6
Do.	do.	5.2
Juncos clay	do.	51.6
Las Piedras clay loam	do.	7.1
Humacao loam	do.	11.4
Teja loam	do.	8.2
Moca clay	Red and Yellow Podzolic	34.1
Lares clay	do.	16.5
Do.	do.	13.7
Cabo Rojo clay	do.	14.1
Do.	do.	26.9
Los Guineos clay	do.	8.7
Do.	do.	20.9
Fajardo clay	do.	14.5
Jayuya silty clay loam	do.	12.1
Vía silty clay	do.	13.0
Do.	do.	18.1
Catalina clay	Reddish Brown Lateritic	10.8
Do.	do.	8.4
Catalina stony clay	do.	11.2
Catalina clay, level phase	do.	10.9
Cialitos clay	do.	14.9
Alonso clay	do.	24.0

[1] Guánica, Jácana, Fraternidad, Santa Isabel, Amelia, and Llave are soils of the arid region; Paso Seco and Machete of the semiarid; all others of the humid regions.

TABLE 4.—*Continued*

Soil type	Soil group	Milliequivalents per 100 gm. of dry soil
Matanzas clay	do.	7.1
Bayamón sandy clay	do.	5.2
Río Piedras clay	do.	15.9
Sabana Seca sandy clay	Ground Water Laterite	7.1
Caguas clay	do.	12.0
Coto clay	Yellowish Brown Lateritic	7.7
Nipe clay	Laterite	2.1
Do.	do.	3.2

so in the lateritic groups, as indicated by the low total exchange capacity 5 to 8 m.e., that points to the presence of kaolinlike minerals as reported by Bonnet (1) for Catalina clay, a lateritic soil. Jeffries et al. (4) will later publish a paper on the identification of minerals in soils of Puerto Rico with low and high exchange capacities.

The highest value obtained for total exchangeable bases (table 3) was 60.4 m.e. per 100 gm. of soil for Aguirre clay, an alluvial soil, and the lowest was 1.81 m.e. for Coto clay, a lateritic soil at a depth of 7 to 17 inches. The content of exchangeable calcium (Ca) was about 80 percent for the former soil and about 32 percent for the latter, but rose as high as 94 percent in Ponceña clay, a Chernozem. The calcium-to-magnesium ratio varied from 1.2 in the Coto clay to 321 in the Aguirre clay reported above. The exchangeable potassium (K) varied from 0.12 to 2.73 m.e. per 100 gm. of soil, and the exchangeable sodium from 0.26 to 11.00, the latter in a saline Aguirre clay.

SUMMARY

Data are presented here for the total exchange capacity of 81 soil samples in Puerto Rico and for available cations: Calcium, magnesium, potassium, and sodium, in 30 soil samples. The soils analyzed were representative of the following 13 groups: Rendzina, Wiesenboden, Reddish Brown, Reddish Chestnut, Reddish Prairie, Gray Brown Podzolic, Red and Yellow Podzolic, Reddish Brown Lateritic, Yellowish Brown Lateritic, Ground Water Laterite, Laterite, Lithosols, and Alluvial. Exchangeable bases are also reported for some soils in the Chernozem group.

The highest value obtained for total exchange capacity was about 64 milliequivalents per 100 gm. of dry soil for a Rendzina and the lowest was about 2 m.e. for a Laterite. There is a wide difference between the minimum and maximum values of total exchange capacity for the various soil groups. Weathering had been active in the podzolic and more so in the lateritic group.

The highest value for total exchangeable bases was over 60 m.e. for an Alluvial soil and the lowest was less than 2 m.e. for a lateritic soil; these contained 80 and 32 percent, respectively, of exchangeable calcium.

TABLE 5.—*Total exchange capacity of some soil types*[1] *in some azonal soil groups of Puerto Rico*

Soil type	Soil group	Milliequivalents per 100 gm. of dry soil
Múcara silty clay loam	Lithosols	8.2
Do.		36.0
Do.		40.0
Múcara silt loam		20.7
Pandura sandy clay loam		19.3
Tanamá stony clay		8.5
Guayama loam		19.3
Descalabrado silty clay		17.0
Vega Baja silty clay	Alluvial	17.7
Coloso silty clay		32.1
Do.		38.6
Toa loam		14.7
Toa silty clay loam		23.6
Do.		35.0
Estación silt loam		13.1
Viví sandy loam		7.7
San Antón clay loam		31.4
San Antón loam		26.6
Do.		23.7
Vayas silt loam		46.0
Aguirre clay		28.0
Do.		42.1
Do.		43.8
Do.		45.0
Do.		45.8
Do.		48.2
Do.		50.4
Do.		52.2
Do.		54.4
Do.		60.2
Do.		60.3

[1] Guayama, Descalabrado, San Antón, Vayas, and Aguirre are soils of arid area; all others of the humid area.

RESUMEN

En este trabajo se informan las capacidades totales de intercambio para 81 muestras de suelos en Puerto Rico y los cationes intercambiables: calcio, magnesio, potasio, y sodio, para 30 muestras de suelos. Los suelos

analizados representan los siguientes 13 grupos: Rendzina, Wiesenboden, Rojos Pardos, Rojos Castaños, Rojos de Pradera, Podsólicos Gris Pardos, Podsólicos Rojos y Amarillos, Lateríticos Rojizos Pardos, Lateríticos Amarillentos Pardos, Lateritas Hidropédicas, Laterita, Litosoles y Aluviones. Se informa también el contenido de bases intercambiables para algunos suelos en el grupo Chernozem.

El valor más alto que se obtuvo para la capacidad total de intercambio fué de 64 miliequivalentes por 100 gramos de tierra seca para un Rendzina y el más bajo fué de 2 m.e. para un suelo laterítico. Hay una variación grande entre los valores mínimos y máximos de la capacidad total de intercambio para varios de los grupos de suelos. El proceso de meteorización ha sido activo en los suelos Podsólicos y más aún en el grupo de los Lateríticos.

El valor más alto para el total de bases intercambiables fué de 60 m.e. para un suelo de aluvión y el más bajo fué de 2 m.e. para un suelo laterítico con 80 y 32 por cientos, respectivos, de calcio intercambiable.

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UTILIZATION OF ORGANIC SOILS IN PUERTO RICO

M. A. LUGO-LÓPEZ AND J. A. BONNET[1]

INTRODUCTION

In Puerto Rico, as in the world as a whole, soils are mostly of a mineral nature with small, varying quantities of organic constituents. This organic fraction, however, is so important that the term "organic soils" has been used in connection with those in which the organic matter content is above 15 percent in contrast to "mineral soils" wherein the organic constituents are decidedly less. There are more than 25,000 acres of organic lands in Puerto Rico that still lie untilled, mostly because of very poor natural drainage, complicated sometimes, by the presence of harmful alkali salts in the profile. When properly drained and managed these peats and muck lands perhaps will rank among the most productive soils of the Island.

Zerban (12)[2] studied, the salt marshes of the north coasts of Puerto Rico in a preliminary way. His main objective was to determine the endurance limit of cane grown under various saline levels at different places. Bartel (2) established a basis for the selection of pumps to drain the coastal swamps of Puerto Rico by using drainage coefficients based on rainfall-frequency studies. Gruz Monclova (5) conducted preliminary work on soil salinity at the Guánica, Aguirre, Lafayette, and Tiburones areas. Dachnowski-Stokes and Roberts (6) reported morphological studies of several saline peat profiles of Puerto Rico.

Organic lands present problems of soil management quite distinct from those of mineral soils. Their reclamation is expensive. Their ground water table has to be lowered to a level where it will allow adequate aeration for successful crop production. The harmful alkali salts, if any, must be leached. This can be accomplished through drainage—tiles, ditches, pumps, dams, and other devices required to control the ground waters; with chemicals such as sulfur and gypsum, and by irrigation with fresh waters to leach out the toxic salts. However, experience from other areas seems to indicate that the productive capacity of these lands will justify economically the expenditures required. Such has been the case of the Fens of England, the "veens" of Holland, the Everglades of Florida, and the muck lands of Michigan, Minnesota, New York, and other areas (1, 7, 8). To the Island of Puerto Rico with its extremely meager land resources, the reclamation has still greater meaning: It will provide more food for the population, more income for the Government, more trade volume, and more wealth.

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[2] Figures in parentheses refer to Literature Cited, p. 65.

ORIGIN OF ORGANIC SOILS IN PUERTO RICO

Organic soils have been formed from the accumulation of leaves, twigs, roots, and other materials in lagoons and bays. Dachnowski-Stokes and Roberts (6) report two types of peat in Puerto Rico: The Ensenada Honda peat, and the Martin Peña peat, and one type of muck, the Caño Tiburones muck. The first peat consists of one continuous layer of mangrove peat, and the second of two layers: A surface fibrous mangrove peat over a layer of marine sedimentary peat. The muck consists also of two layers: An upper sedimentary muck over a tule peat.

A monolithic sample of the Ensenada Honda peat, collected about 2 km. east of Ensenada Honda, at the east coast of Puerto Rico, is described by Dachnowski-Stokes and Roberts (6) as follows:

"Mangrove peat: 0 to 101.6 cm. brown to reddish-brown, coarse but firm fibrous peat, consisting chiefly of a porous, interlacing network of fine rootlets, yellowish-brown in color, brittle when dry, crumbling into small particles. Embedded in the tangle of rootlets are relatively small quantities of dark colored, finely divided organic sediments carried by tides and waves of sea water. A prominent feature is considerable amounts of stout roots of mangrove, the pith of which is in varying states of decomposition. The whole profile section is indistinctly differentiated, free from woody fragments and plant remains of secondary species, contains little material and is but feebly altered by soil making processes; it is the product of the roots and rootlets from a pure stand of mangrove. Soluble salts are present in the entire profile in amounts ranging between 3 and 5.5 per cent and the reaction of the air-dried material is strongly acid (pH 4.3–4.6). The thickness of the layer varies in places from 1 to 1.5 m. and rests abruptly on coarse white sand of unknown depth."

A profile of the Martín Peña peat, collected about 1.5 km. east of the Martín Peña railroad station, at Río Piedras, is described (6) as follows:

"Mangrove peat: 0 to 28 cm.; thin surface cover of black, sticky organic tidal ooze containing an occasional mollusk shell; the sediment varies in thickness from 5 mm. to 1.5 cm. Below it is reddish-brown, coarsely, fibrous, matted mangrove peat which consists of a tangle of yellowish colored fine rootlets and large reddish-brown pithy aerial and lateral roots of mangrove (species of Rhizophora and Avicennia) embedded in black, finely divided organic residue. The material contains about 3 per cent of soluble salts and has a moderately acid reaction (pH 5.6).

"28 to 61 cm.; finely fibered, very dark brown to mottled, more or less firm mangrove peat; it consists of a large proportion of black organic residue held in a meshwork of fine yellowish rootlets and is penetrated by a few stout, branching pithy roots in varying states of decomposition.

The material is saline and acid (pH 5.1).

"Sedimentary peat: 61 to 92 cm.; grayish-black, soft, oozy mixture composed chiefly of organic residue of the size of colloidal particles, together with gray colored fine rootlets. The layer is penetrated by a few pithy roots of mangrove; it becomes dense and hard when dry and breaks with smooth fractures. The content of soluble salts varies between 3 and 3.5 per cent and the reaction is moderately acid (pH 5.6).

"At a depth ranging from 1 to 1.5 m., the underlying mineral soil is bluish green to gray plastic clay."

A profile of Caño Tiburones muck collected from the eastern part of Caño Tiburones swamp, about 15 km. east of Arecibo, is described (6) as follows:

"Sedimentary muck: 0 to 26 cm.; under cultivation; the material at the surface develops a black, granular muck, more or less mineralized; it contains insects and worms. Downward it continues into sticky plastic sedimentary peat of heavy texture, dense, compact and hard when dry, tending to break into angular cloddy aggregates that later disintegrate into loose granules. The cultivated material is neutral in reaction (pH 7.3).

"Tule peat: 26 to 58 cm.; black, stringy fibrous peat consisting mainly of soft, partly decomposed vertical stems and the rootstocks of tule (Scirpus sp., Eleocharis sp. and others), embedded in sticky plastic organic residue derived from secondary herbaceous plants. The material contains very small amounts of soluble salts, is slightly acid in reaction (pH 5.9) and shows a tendency to compaction and hardening when dry.

"58 to 63 cm.: band of dark gray clayey mineral material probably due to flood water; it is mottled with black organic residue and channeled vertically with partly decomposed, flattened culms of tule sedges (Scirpus sp.); the material is moderately saline and acid in reaction.

"63 to 90 cm.: coarse stringy-fibrous tule peat, very dark brown to black, consisting largely of vertical, partly decomposed, more or less flattened stems of tule (Scirpus sp.) in a matrix of plastic amorphous organic residue. No visible alterations have taken place in the material during the period of time it has been buried by the mineral sediments. The content of soluble salts is fairly high, and the reaction is strongly acid (pH 4.2). The thickness of the layer extends to a depth of 1½ m. below the surface and the underlying mineral material is a bluish-gray, plastic clay."

Dachnowski-Stokes and Roberts (6) say:

"It is apparent that Caño Tiburones first developed as a marsh characterized by fresh or brackish water in which tall-stemmed rushes (Scirpus sp.) were dominant and persisted in great abundance as the pioneer plant community. The profile section also indicates a sudden inflow of erosion water that carried with it large quantities of clayey sediments. Flooding, that may be attributed to a period of very moist climatic conditions, or else subsidence, appears to have continued down to recent times. The change brought about a stand of water so nearly fresh that aquatic vegetation, forming sedimentary peat, replaced the tule marsh. The vegetation dominating at the present time is associated in places with saline conditions due to the entrance of tide water, but no particular part of it has, as yet, contributed to the development of fibrous peat."

DISTRIBUTION

The organic soils, called either Bogs or Half-Bogs, depending on the depth of the organic layers, are confined to the coastal lowlands of the Island. They are waterlogged most of the year because of their topographic position and their proximity to the oceanic waters. The characteristic vegetation consists of mangroves, sawgrass, sedges, cattails, reeds, ferns, and similar types of water-loving plants. Table 1 shows the series of organic soils of Puerto Rico and their extent in acres.

Twenty-four percent of the organic lands have been classed as Tiburones muck. The most extensive belt of this soil occurs in northern Puerto Rico in the Arecibo-Barceloneta region where the average rainfall fluctuates around 60 inches per annum. Other areas are found north of Central Canóvanas, and near Lago Tortuguero. Slightly over 3 percent of the area has been reclaimed and is being cultivated. Under the farm practices of the region, yields of 45 tons of ratoon cane have been obtained, averaging about 8 to 10 percent of sucrose. Good yields of cabbage have been obtained on a very limited acreage. Some areas are devoted to forage crops and the amount of malojillo produced is quite acceptable. In certain areas alkali salts are found in harmful concentrations—the surface soil at times showing a white crust of salts during dry periods. This mostly results from flooding by sea water in the extremely low places, particularly during high tides when the outlet of the old "Caño Tiburones" remains clogged for relatively long periods.

TABLE 1.—*Distribution of organic soils in Puerto Rico*

Soil series	Soil group	Acres
Tiburones muck	Bog	6,848
Saladar muck	do.	8,000
Saladar muck, shallow phase	Half-Bog	1,152
Peat	Bog	7,360
Peat, shallow phase	Half-Bog	1,280
Reparada	do.	2,560
Ursula	do.	1,088
Total		28,180

Saladar muck, considered together with its shallow phase, is the most extensive bog soil of the Island. It occurs in narrow strips along the north, east and west coasts under various local climatic belts: In Mandry (east of Central Pasto Viejo, Humacao), Puerto Nuevo, Toa Baja, east of San Juan, east of Arroyo, Guanajibo, Boquerón (near Laguna Rincón), southeast of Fajardo, northwest of Isabela, and in a number of other places. Small areas are planted to sugarcane near Arroyo in the southeast, and in Mandry in the east, but for the most part the land is not being used agriculturally. Toxic quantities of alkali salts and the low position, favorable for further flooding, at present prevent the economic utilization of most of these muck lands.

The largest areas of bog soils under cultivation in Puerto Rico are those classified as Peat which, under efficient management, yield from 35 to 45 tons of sugarcane per acre in regions where the precipitation fluctuates around 75 inches annually. Large tracts of peat occur around Loíza and

Carolina, and are relatively free from harmful alkali salts. There is a fair-sized area west of Cataño extending around San Juan Bay and in strips alongside Caño Martín Peña to Lago San José. Other areas of Peat are found in the east coast around Ensenada Honda and in the South around Puerto Jobos. Areas of the shallow phase are found east of San Juan and in close association with typical Peat soil.

Reparada and Ursula are the two organic soils of arid and semiarid Puerto Rico. They both occur in the southern and southwestern coasts—southwest of Ponce, near Caleta de Cabullón, in Punta Guayanilla, south of Central Rufina, in Punta Tocón, southwest of Lajas, and in other places of similar ecology. They are both subject to inundations during high tides. If drained, and if the salts are washed off, sugarcane grows well on these soils. Yields of 30 to 35 tons per acre have been reported. The area now under cultivation is very restricted; the majority of the lands being very salty. The Reparada soil covers an area over 2,500 acres, about 9 percent of the total organic soil area of Puerto Rico, and the Ursula more than 1,000 acres or 3 percent. Both of these soils occur in the extremely dry region of southern Puerto Rico, where rainfall never surpasses the 25- to 35-inch level. Because of their low geographical position they receive waters from the uplands nearby and from the Caribbean Sea, which causes a nearly constant waterlogged condition. This accounts for the fact that the vegetation is not typical of the arid zone where these half-bogs occur. The combination of hydrophytic and halophytic plants which thrive on these areas is rather an expression of local soil conditions than of the zone as a whole.

MATERIALS AND METHODS

The distribution of the organic lands of Puerto Rico was determined from the maps prepared in connection with the Soil Survey of Puerto Rico (11). Samples were taken at several sites following the technique of Cline (4). They were passed through a 2-mm. sieve. Undisturbed soil cores were also taken for bulk density determinations.

Conductivity measurements were done in 1:2 soil-water suspensions by using the standard solu-bridge. Bulk density was determined by drying a sample of known volume in an oven to 105°C. The picnometer was used for specific gravity measurements. The total porosity was calculated from the well-known relation between bulk density and specific gravity.

CHEMICAL PROPERTIES

No organized effort has been made to study the chemical nature of the organic soils of Puerto Rico. Experience in other areas seems to indicate that, when drained, they are capable of producing a few crops successfully

without appreciable expenses in fertilizer applications. A rational program of fertilization must be established, if profitable yields are to be expected.

Chemical data, as adapted from Bonnet (3), are presented on table 2. The reaction of the soils studied range from acid to alkaline, according to their climatic region. On the percentage basis they seem to be well supplied with nitrogen, and available phosphorus and potassium, and are quite high in available calcium. However the organic soils contain less total nutrients than the average mineral soil because of their lower weight per given volume of soil.

TABLE 2.—*Chemical data for the surface layer of some organic soils of Puerto Rico*

Soil type	Location	pH	Total nitrogen	Organic matter	1-percent citric acid solution		
					P_2O_5	CaO	K_2O
			Percent	*Percent*	*Percent*	*Percent*	*Percent*
Peat	Aguadilla-Maleza Alta, 1 km. North of San Antonio	8.5	0.24	—	0.012	0.932	0.043
Saladar muck	6 kms. East of Toa Baja	5.1	1.54	51.3	.024	.638	.081
Reparada clay	35 spaces West of Hacienda Reparada	8.1	.29	—	.021	2.350	.011
Ursula clay	Ponce area	8.7	.28	—	.016	.847	.035

TABLE 3.—*Specific conductance of the surface layer of some organic soils of Puerto Rico*

Type	Conductivity (mhos. $\times 10^{-6}$ at 25°C)
Peat	2,100
Peat, shallow phase	2,250
Reparada clay	2,400

In table 2 it may be seen that the organic matter of a sample of Saladar muck accounts for more than half of its total weight. Studies of peat soils near San Juan area indicate that their organic matter content fluctuates between 20 and 28 percent (9).

Table 3 gives values for specific conductance in the surface layer of some organic soils of Puerto Rico.

The content of salts is very high indeed as indicated by the conductivity values given in table 3. However, such is not the case for all organic soil areas. The extent to which salinity problems may complicate the reclamation of Puerto Rican Bogs and Half-Bogs remains yet to be determined.

PHYSICAL PROPERTIES

Table 4 shows that the organic soils are very light in weight. In three instances, bulk density values are below 1.00 gm./cc. Mineral soils usually

show higher values which increase with increases in the proportion of sand. Values for total porosity show considerable variability. They fluctuate from nearly 60 to almost 70 percent, which are high as compared to values for the average mineral soil.

Moisture studies indicate that peat soils around the San Juan area, as a rule, contain about 45 percent of water by volume at field capacity (9). Those values are higher than the corresponding ones for mineral soils and indicate that bog soils have a high water-holding capacity. Nevertheless, their available water may be even less than that of mineral soils, because wilting occurs at a very high moisture content. Plants have been observed to wilt permanently even when the soil still had moisture amounting from half to three-fourths of their total water retaining capacity. It seems that water is retained too strongly and is to a large extent unavailable for plants.

TABLE 4.—*Bulk density and porosity of the surface layer of several organic soils of Puerto Rico*

Soil type	Bulk density (gm./cc.)	Porosity (percent by volume)
Peat	0.79	59.25
Peat, shallow phase	.99	62.98
Tiburones muck	.87	68.61
Reparada clay	1.06	59.97
Ursula clay	1.10	58.38

OTHER CONSIDERATIONS

The drainage of the Caño Tiburones is already under way and will make available for cultivation about 5,600 acres of land at an approximate total cost of $1,500,000 or about $267 per acre (10). Bartel estimates that drainage of large areas of 500 acres, or more, will cost under $300 per acre, while that of smaller areas will cost around $500 (2). In all probability the cost of draining the coastal swamps and the leaching of the toxic salts, where feasible, will be costly, but Puerto Rico cannot afford to leave any area unreclaimed that may increase to any extent—no matter how limited it might seem—the arable lands of the Island. The Bogs and Half-Bogs after being drained and leached of harmful salts or reclaimed with chemicals if necessary, will provide a considerable area of land that can be adapted to the intensive cultivation of cash crops, such as sugarcane and vegetables. High yields of truck crops have been obtained in other areas. A good cane tonnage has been obtained in Puerto Rico in the limited acreage of these soils fit for agricultural operations (11). It can reasonably be expected that higher yields can be obtained after draining, if a truly scientific approach is made toward the utilization and efficient management of these lands.

The lowering of the ground water table of cultivated organic soils will eventually lead to the subsidence or settling of the land. Even at the starting point, there must be a conservation program to reduce or prevent losses of soil in muck lands. A sound program of fertilization should be developed at an early date, to keep the organic soils productive for a long time, because their natural fertility will only last a short period. A detailed program of research should be conducted to determine the most profitable and efficient management of peat and muck lands in Puerto Rico.

SUMMARY

There are more than 25,000 acres of organic soils in Puerto Rico, of which approximately 10 percent are under cultivation. They occupy very low topographical positions and in many instances brackish waters affect the profile. They were formed from the accumulation of leaves, twigs, roots, and other materials in lagoons and bays. The characteristic vegetation consists primarily of mangroves associated with other hydrophylic plants. Tiburones muck and Saladar muck make up more than 50 percent of the total acreage of Puerto Rican organic soils. These soils are generally well supplied with humus and nitrogen. Although they seem to be well supplied with calcium, and available phosphorus and potassium, it should be remembered that they contain smaller total amounts of these nutrients than the average mineral soil, because of their lighter weight per unit volume. From the physical point of view they seem to be well adapted to cultivation and rather easy to handle, if a sound program of management and conservation is followed. In cultivated areas yields of 45 tons of ratoon cane per acre have been obtained under the local management methods of the region, without a precise knowledge of the properties of organic soils, which probably require more specialized techniques to attain maximum yields and higher quality crops. The total cost of draining the marshes, where practicable, as well as of getting rid of the harmful salts, if present, will be high, but its beneficial effect on the economy of Puerto Rico can be far reaching.

RESUMEN

En Puerto Rico hay más de 25,000 acres de terrenos orgánicos de los cuales un 10 por ciento aproximadamente, se encuentra ahora bajo cultivo. Estos suelos están a niveles muy bajos y en muchos casos el agua del mar los afecta adversamente. Se formaron de la acumulación de hojas, ramas, raíces, y otros materiales en lagunas y bahías. El mangle y otras plantas hidrofílicas constituyen la vegetación típica de esos terrenos. Más de la mitad del área total de los suelos orgánicos de Puerto Rico pertenece a las series "Tiburones muck" y "Saladar muck." Estos suelos orgánicos son

generalmente ricos en humus y nitrógeno y tienen un alto por ciento de calcio, fósforo y potasio asimilables, pero debido a su bajo peso por volumen tienen menores cantidades de estos nutrimentos que el suelo mineral típico. Son fáciles de cultivar pero es necesario manejarlos apropiadamente. Bajo nuestras condiciones locales, y sin técnicas especiales de cultivo, estos suelos han llegado a producir hasta 45 toneladas de caña por acre. El costo total de desagüe de estos suelos y del lavado de sales que habría que hacer en algunos casos, será alto, sin embargo, su efecto en la economía del país puede ser muy favorable.

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FUNCTIONAL RELATIONSHIPS BETWEEN MOISTURE AT SEVERAL EQUILIBRIUM POINTS AND THE CLAY CONTENT OF TROPICAL SOILS

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INTRODUCTION

It is generally accepted that soils are able to hold moisture in proportion to their content of clay particles, provided their clay complex is similar mineralogically, and that their level of organic matter is more or less on an equal basis. In temperate regions, attempts have been made to measure quantitatively the influence of the clay fraction in the ability of the soils to retain moisture at various levels. No similar work, however, has been reported from workers in the Tropics. This paper presents the results of an attempt to evaluate the moisture content throughout the whole pF range of Puerto Rico soils on the basis of their percentage of clay.

It is of fundamental importance to establish with certainty the nature of such a relationship. If reliable regressions are obtained, agronomists and practical agriculturists will have an easy way to make acceptable predictions concerning the moisture relationships of tropical soils on the basis of their clay content.

MATERIALS AND METHODS

Samples were collected in the humid region in areas where lateritic soils are predominant and in areas of nonlateritic soils. Seventy-one sites were sampled, 19 of which occur in the former area and 52 in the latter. In sampling an area, the maps of the Soil Survey of Puerto Rico were used as a guide in the field (5).[2] The soil descriptions were checked with field observations to make certain that the samples corresponded to the series under consideration. Composite samples were obtained following the procedure outlined by Cline (2) from the topmost 6 to 8 inches. Each composite consisted of several units. The samples were then air-dried and passed through a 2-mm. sieve. Undisturbed cores of soil were also taken for bulk density determinations.

Total porosity values were taken as indices of the maximum saturation values for each soil. To estimate the porosity, true density was determined by using the picnometer, and bulk density by drying an undisturbed core of soil to constant weight at 105°C. Field capacity measurements were made by using the technique suggested by Weaver and Clements (8).

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[2] Numbers in parentheses refer to Literature Cited, pp. 69–70.

The moisture equivalents were determined by means of a special centrifuge following the method outlined by Briggs and McLane (1). The standard biological method (6) with soybeans as indicator plants, was used in determining the permanent wilting percentage. Soil samples were brought to equilibrium with 3.3 percent sulfuric acid solution in order to obtain values for hygroscopic coefficients. Clay contents were found by making

TABLE 1.—*Relation between moisture at several critical points and the clay content of lateritic and nonlateritic soils*

Group	Functional relationship	Coefficient of determination[1]	Correlation coefficient[2]
Lateritic	Maximum saturation = 40.90 + 0.44 (percent clay)	0.74	+0.86
	Field capacity = 10.02 + 1.65 (percent clay)—0.020 (percent clay)^2	.83	+.91
	Moisture equivalent = 3.67 + 1.69 (percent clay)—0.018 (percent clay)^2	.84	+.92
	Permanent wilting percentage = 5.80 + 0.53 (percent clay)	.80	+.89
	Hygroscopic coefficient = 3.11 + 0.41 (percent clay)	.71	+.84
Nonlateritic	Maximum saturation = 45.30 + 0.36 (percent clay)	.34	+.57
	Field capacity = 10.98 + 1.70 (percent clay)—0.022 (percent clay)^2	.84	+.92
	Moisture equivalent = 3.56 + 1.89 (percent clay)—0.023 (percent clay)^2	.83	+.91
	Permanent wilting percentage = 3.28 + 0.53 (percent clay)	.76	+.87
	Hygroscopic coefficient = 3.23 + 0.36 (percent clay)	.72	+.85

[1] Is the ratio of the difference between the squared standard deviation and the squared standard error of estimate to the original variability. Indicates the proportion of the variability in moisture which can be explained on the basis of the clay content.

[2] Indicates the closeness of the relationship between moisture and clay content.

use of the hydrometer technique (3). The least squares method (4) was employed in the correlation analysis of the data obtained.

PRESENTATION OF RESULTS

The statistical interpretation of the data is presented in table 1 for lateritic and nonlateritic soils.

At maximum saturation, when the total pore space of soils was com-

pletely filled with water, a positive linear correlation was evident in both groups of soils, indicating very moderate increases in saturation with unit increases in clay content. A positive correlation coefficient of the order of 0.86 was obtained for lateritic soils which explains three-fourths of their variability in moisture at the uppermost range of the scale on the basis of the percentage of clay particles. In nonlateritic soils of the humid Tropics only one-third of the variability observed could be accounted for by taking the clay content as a basis independently from other factors.

A highly significant correlation is evident between the moisture retained at field capacity by both lateritic and nonlateritic soils and that fraction of the soil dominated by particles smaller than 0.002 mm. More than 80 percent of the variability in field capacity can be ascribed to variations in clay content. In both groups of soils there is a marked tendency for increasing moisture values to occur with increasing clay contents until a certain level is reached. Afterwards, the increases in clay accompany increased moisture at only a decreasing rate until a point is reached where further increments of clay have no effect on the water-retaining power of the soil.

The same general relationship holds between moisture equivalent and clay. The same curvilinear pattern is observed as indicated by the regressions on table 1. The correlation is also highly significant in this case when only about 16 and 17 percent of the variability observed for lateritic and nonlateritic soils, respectively, cannot be explained on the exclusive basis of the clay content of the soil.

A definite linear relationship exists between the permanent wilting percentage and the clay content. The correlation for all humid soils is very high indeed. The clay content explains more than 80 percent and 75 percent of the variability occurring in the permanent wilting percentages of lateritic and nonlateritic soils respectively.

The soils of the humid Tropics continue to exhibit a very close degree of association between their moisture equilibrium points and their clay percentage, even at the lower end of the range represented by the hygroscopic coefficient. The variability in moisture content at that point is mostly accounted for by the variation in clay content of the soils.

DISCUSSION

The relationships presented indicate that rather accurate predictions of the moisture content at all equilibrium points can be made on the basis of the percentage of clay in the lateritic soils. As for the nonlateritic soils of the humid area, it is apparent that very significant predictions are possible in the lower and middle scale of moisture values ranging from hygroscopic

coefficient to field capacity. However, as the point of maximum saturation is approached, the clay content can no longer be used as a very reliable index. The regressions presented in table 1 are particularly valuable, since they facilitate the evaluation of several physical constants of the soil without their direct determination. A knowledge of the clay content of soils of the humid Tropics can serve as a key to a rather precise body of information concerning their moisture relationships.

SUMMARY

The tropical soils of the humid region studied in this investigation have been grouped into two broad categories: (a) Lateritic and (b) nonlateritic. Regression equations are presented which may serve to predict any of the moisture constants considered, namely, maximum saturation, field capacity, moisture equivalent, permanent wilting percentage, and hygroscopic coefficient, on the exclusive basis of the clay content of the soils. Very high correlations were obtained in all cases for lateritic soils. Very high correlations were also found for the nonlateritic soils of the humid Tropics, excepting the values for maximum saturation.

RESUMEN

Los suelos tropicales de la región húmeda de Puerto Rico que se usaron en esta investigación fueron agrupados en dos categorías: (a) Lateríticos y (b) no-lateríticos. Se presentan ecuaciones de regresión que pueden servir para predecir, a base del contenido de arcilla de los suelos exclusivamente, las constantes estudiadas, a saber: Saturación máxima, capacidad de campo, equivalente de humedad, punto de marchitez permanente y coeficiente de higroscopicidad. Se obtuvieron índices de correlación altamente significativos en cada caso para suelos lateríticos. En suelos no-lateríticos la correlación fué también altamente significativa en todos los casos con excepción de la correlación entre la saturación máxima y el contenido de arcilla.

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THE EFFECT OF FERTILIZERS ON THE YIELD AND QUALITY OF SWEETPOTATOES

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INTRODUCTION

The sweetpotato occupies an important place in the Puerto Rican diet. It is of nutritional importance, not only for its high caloric value, but for its abundant vitamin content, especially vitamin A. The yellow-fleshed variety U.P.R. No. 3, for instance, is exceptionally high in carotene, thus providing an inexpensive and abundant source of vitamin A for man and animal.

The cultivation of sweetpotatoes ranks as one of the more important food crops of Puerto Rico. They are grown in all areas of the Island. From 1944 to 1948, the average production per year of the sweetpotato crop in the Island amounted to 1,601,355 hundredweights at a mean cash value of $3,120,000 annually (2).[2] The majority of the crop grown receives little or no fertilizer and a minimum of care. In general, the sweetpotato crops are grown on poor or marginal land with little attention to proper agronomic practices. The purpose of this work was to determine not only the major fertilizer (N-P-K) requirements, but also minor-element requirements, and the effect of fertilizers in general on the quality of sweetpotatoes as reflected in the starch and carotene content.

EXPERIMENTAL PROCEDURE

The investigation consisted of four field experiments covering a range of soil textures from loamy sand to heavy clay. The Loiza experiments I and II were established on Cataño loamy sand, a well-drained coastal lowland soil, alkaline in reaction (pH 7.6), devoted mostly to coconuts, citrus, sweetpotatoes, cassava, beans, and peanuts. The Sabana Seca experiment was conducted on Sabana Seca sandy clay loam, a coastal plain soil, which has a friable surface soil (pH 6.3) and a heavy plastic subsoil, and is under cultivation mostly to minor truck crops. The Corozal experiment was established on Lares clay, a lateritic acid clay (pH 4.5) of the terrace and alluvial fans of Puerto Rico, cropped mainly to sugarcane and pineapples.

The fertilizer treatments for the four experiments consisted of varying increments of nitrogen (N), phosphorus (P_2O_5), and potassium (K_2O).

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[2] Figures in parentheses refer to Literature Cited, p. 86.

Filter-press cake (a product of the sugar mills) applications and liquid fertilizer treatments were also used. The minor-element treatments included applications of copper, boron, manganese, magnesium, and calcium. The exact rates of application are described in the tables. All fertilizers were applied 15 days after planting, using the band method.

TABLE 1.—*Influence of major-element fertilizers on the yields of sweetpotatoes: Loiza experiments I and II on Cataño Loamy Sand and the Sabana Seca experiment on Sabana Seca Sandy Clay*[1]

No.	Treatment and rate of application per acre			Loiza experiment I: Mean yield per acre	Loiza experiment II: Mean yield per acre	Sabana Seca experiment: Mean yield per acre
	N	P_2O_5	K_2O			
	Pounds	*Pounds*	*Pounds*	*Hundredweights*	*Hundredweights*	*Hundredweights*
1	0	200	200	102	43	63
2	82	200	200	130	47	119
3	165	0	200	114	49	108
4	165	100	200	116	46	112
5	165	200	0	68	43	98
6	165	200	100	78	39	116
7	165	200	200	107	42	100
8	165	300	200	89	—	113
9	165	200	300	119	41	112
10	165	300	300	119	45	108
11	82	100	50[2]	92	45	98
12	18	18	9[2]	70	—	60
13	10 tons filter-press cake			—	29	—
14	20 tons filter-press cake			—	31	—
15	100	100	100	—	57	—
	10 tons filter-press cake					

[1] Least significant differences needed for comparison at:

5-percent point	39	14	15
1-percent point	52	19	20

[2] 1,000 pounds of a 8–10–5 commercial fertilizer per acre.

[3] Liquid fertilizer formula of 8–10–5 at rate of 17.5 gallons per acre which is equal in price to 1,000 pounds of a 8–10–5 commercial fertilizer.

The experimental design for all four experiments was a triple lattice with six replications of each treatment. The plot size was 20 feet long by 8 feet wide or one two-hundred-and-seventy-second of an acre. The propagating material consisted of 40 vine cuttings (the first 18 inches of the sweetpotato vine being used) per plot of U.P.R. No. 3, an outstanding Porto Rico sweetpotato variety developed by the Plant Breeding Department of this Station. The vines were planted in four furrows, 2 feet apart and 3 to 4 inches deep.

The carotene content and starch analyses were conducted on random

samples of 10 sweetpotatoes per plot. In all cases, the same general shape and size were used which conformed with the U. S. No. 1 root. The material was prepared for analyses from 24 to 48 hours after harvesting. The carotene content was determined by the method of Moore and Ely (9) and starch by the method of Nielson (10).

TABLE 2.—*Influence of major-element fertilizers on the yields of sweetpotatoes: Corozal experiment on Lares Clay*[1]

No.	Treatment and rate of application per acre			Soil pH[2]	Mean yield per acre
	N	P_2O_5	K_2O		
	Pounds	*Pounds*	*Pounds*		*Hundredweights*
1	0	200	200	6.0	139
2	82	200	200	6.0	107
3	165	0	200	6.0	94
4	165	100	200	6.0	88
5	165	200	0	6.0	94
6	165	200	100	6.0	106
7	165	200	200	6.0	78
8	165	300	200	6.0	119
9	165	200	300	6.0	94
10	165	300	300	6.0	116
11	0	200	200	4.5	96
12	82	200	200	4.5	68
13	165	200	200	4.5	60
14[3]	165	200	200	4.5	85
15[3]	165	200	200	6.0	114
16[4]	82	100	50	6.0	93
17	0	0	0	6.0	81

[1] Least significant difference needed for comparison at:

5-percent point	24
1-percent point	31

[2] Normal soil pH 4.5; soil raised to pH 6.0 with 7,500 pounds $CaCO_3$ per acre.

[3] Plus 20 tons of filter-press cake.

[4] As 1,000 pounds of 8–10–5.

EXPERIMENTAL RESULTS

The results of the effect of the fertilizer treatments on yields and carotene and starch contents of the sweetpotatoes are given in tables 1 to 9. The major-element fertilizer (N-P-K) effects on yields are presented in tables 1 and 2, and the lime and minor-element fertilizer results in tables 3 and 4. The effects of major-element fertilizers on carotene and starch contents are given in tables 5 and 6, and of minor-element fertilizers on the same in tables 7 to 9. The hundredweight unit reported in yields represents U.S. No. 1, No. 2, and Jumbo grades. The carotene content is given

in both the fresh-weight basis at time of harvest and the dry-weight basis (80°C.). The starch content is given on the dry-weight basis (80°C).

Influence of Major-Element Fertilizer on Yields

Nitrogen

The use of nitrogen influenced the yields of sweetpotatoes. In 2 of the 4 experiments an application of 165 pounds of nitrogen per acre was excessive.

TABLE 3.—*Influence of lime and minor-element fertilizers on the yields of sweetpotatoes: Loiza experiments I and II on Cataño Loamy Sand and the Sabana Seca experiment on Sabana Seca Sandy Clay*[1]

No.	Treatment[2]		Loiza experiment I			Loiza experiment II			Sabana Seca experiment		
	Element	Form applied	Rate of application per acre	Mean yield per acre	Relative yield	Rate of application per acre	Mean yield per acre	Relative yield	Rate of application per acre	Mean yield per acre	Relative yield
			Pounds	*Hundredweights*	*Percent*	*Pounds*	*Hundredweights*	*Percent*	*Pounds*	*Hundredweights*	*Percent*
1	None	—	—	107	100	—	42	100	—	100	100
2	Boron	Borax	30	113	105	50	45	107	30	116	116
3	Magnesium	Magnesium oxide	50	118	110	200	50	119	100	112	112
4	Copper	Copper sulfate	25	98	92	—	—	—	—	—	—
5	Manganese	Manganese sulfate	25	96	90	—	—	—	25	108	108
6	Calcium	Calcium sulfate	—	—	—	—	—	—	500	116	116
7	Boron	Borax	—	—	—	50	55	130	—	—	—
	Magnesium	Magnesium oxide				200			—	—	—

[1] Least significant difference needed for comparison at:

5-percent point	39	14	15
1-percent point	52	19	20

[2] All treatments received fertilizer at the rate of 165 pounds of N and 200 pounds each of P_2O_5 and K_2O per acre.

In the Sabana Seca experiment, the use of 82 pounds of nitrogen gave increases in yields over the zero nitrogen application (table 1). The Corozal experiment gave decreased yields with increased nitrogen applications (table 2). The decreases in yields caused by excess nitrogen were evident both at pH 4.5 (table 2, treatments 11, 12, and 13) and at pH 6.0 (table 2, treatments 1, 2, and 7).

The relative supply of available nitrogen in the soil at Corozal must have been quite high, as the application of 82 pounds of nitrogen gave a

yield decrease. The field where the experiment was conducted was previously in pineapples. These had been heavily fertilized with high-nitrogen fertilizers. It is probable that the residual effect of the nitrogen fertilizer was responsible for the decrease in yield attributed to the application of nitrogen.

TABLE 4.—*Influence of lime and minor-element fertilizers on the yields of sweetpotatoes: Corozal experiment on Lares Clay*[1]

No.	Treatment[2]			Soil pH[3]	Mean yield per acre
	Element	Form applied	Rate of application per acre		
			Pounds		*Hundredweights*
1	None	—	—	4.5	60
2	Calcium	Calcium carbonate	3,500	5.0	76
3	do.	do.	7,500	6.0	78
4	do.	do.	12,500	7.0	90
5	Magnesium	Magnesium oxide	300	4.5	79
6	Magnesium	Magnesium oxide	300	6.0	110
	Calcium	Calcium carbonate	7,500		
7	Magnesium	Magnesium oxide	600	6.0	89
	Calcium	Calcium carbonate	7,500		
8	Boron	Borax	50	4.5	66
9	Boron	Borax	50	6.0	101
	Calcium	Calcium carbonate	7,500		
10	Boron	Borax	50	6.0	103
	Magnesium	Magnesium oxide	300		
	Calcium	Calcium carbonate	7,500		

[1] Least significant difference needed for comparison at:

5-percent point	24
1-percent point	31

[2] All received 100 pounds of N and 200 pounds each of P_2O_5 and K_2O per acre.

[3] Normal soil pH 4.5; soil raised to pH 5.0 with 3,500 pounds of $CaCO_3$, pH of 6.0 with 7,500 pounds $CaCO_3$, and pH 7.0 with 12,500 pounds of $CaCO_3$.

Excessive quantities of nitrogen cause heavy vine growth, and the result is a low yield of poor-quality roots. The general fertilizer recommendation in the United States for sweetpotatoes is 2 to 4 percent of nitrogen at rates of from 1,000 to 1,500 pounds per acre (4).

Phosphorus

In general, there was no effect on yields from the use of phosphorus fertilizers with rates of applications as high as 300 pounds of P_2O_5.

Potassium

The response to potassium was not consistent for the four experiments. Increases in yields were obtained with increasing potassium additions to the soil in the Loiza I experiment (table 1, treatments 5, 6, 7, and 9). This did not occur in the Loiza II experiment. There were no significant consistent responses to potassium in the Sabana Seca and Corozal experiments.

TABLE 5.—*Influence of major-element fertilizers on the starch and carotene content sweetpotatoes: Loiza experiment on Cataño Loamy Sand and the Sabana Seca of experiment on Sabana Seca Sandy Clay*[1]

No.	Treatment and rate of application per acre			Loiza experiment I			Sabana Seca experiment		
				Starch content (dry weight)	Carotene content		Starch content (dry weight)	Carotene content	
	N	P_2O_5	K_2O		Fresh weight	Dry weight		Fresh weight	Dry weight
	Pounds	*Pounds*	*Pounds*	*Percent*	*Mcg./gm.*	*Mcg./gm.*	*Percent*	*Mcg./gm.*	*Mcg./gm.*
1	0	200	200	55	80	269	61	101	322
2	82	200	200	55	87	286	63	124	378
3	165	0	200	51	95	298	62	117	349
4	165	100	200	55	86	269	68	123	363
5	165	200	0	55	133	367	67	129	357
6	165	200	100	50	95	292	66	124	360
7	165	200	200	57	105	338	64	125	379
8	165	300	200	58	103	334	66	122	362
9	165	200	300	58	102	330	66	125	381
10	165	300	300	56	94	291	61	131	375
11	82	100	50[2]	58	96	282	65	117	351
12	18	18	9[3]	49	98	312	61	117	361
[1] Least significant difference needed for comparison at:									
5-percent point				8	23	75	7	15	51
1-percent point				10	31	99	9	20	67

[2] 1,000 pounds of a 8–10–5 commercial fertilizer.

[3] Liquid fertilizer, 8–10–5 at rate of 17.5 gallons per acre.

In the Loiza I experiment, increases in the yields of marketable sweetpotatoes were obtained with increasing potassium applications. This seems to be in close agreement with the work of Scott (11) and others where potassium fertilizers influenced size and shape of the sweetpotato. The general fertilizer recommendation for the United States calls for the use of from 80 to 150 pounds of K_2O per acre (4).

Filter-press cake, Commercial and Liquid Fertilizers

Filter-press cake, when used alone at rates of 10 and 20 tons per acre gave the lowest yields of the Loiza II experiment (table 1, treatments 13

and 14). When used with inorganic sources of N-P-K, it did not give any higher yields than were obtained with fertilizer only (table 1, treatment 15).

The yields obtained with the combination of filter-press cake and inorganic fertilizers were greater than those obtained with filter-press cake alone in the Corozal experiment. The use of filter-press cake with fertilizers

TABLE 6.—*Influence of major-element fertilizers on the carotene content of sweetpotatoes: Corozal experiment on Lares Clay*[1]

No.	Treatment and rate of application per acre			Soil pH[2]	Carotene content	
	NH_3	P_2O_5	K_2O		Fresh weight	Dry weight
	Pounds	*Pounds*	*Pounds*		*Mcg./gm.*	*Mcg./gm.*
1	0	200	200	6.0	126	445
2	82	200	200	6.0	124	422
3	165	0	200	6.0	113	380
4	165	100	200	6.0	118	412
5	165	200	0	6.0	117	396
6	165	200	100	6.0	121	402
7	165	200	200	6.0	124	409
8	165	300	200	6.0	133	445
9	165	200	300	6.0	129	431
10	165	300	300	6.0	123	404
11	0	200	200	4.5	107	367
12	82	200	200	4.5	120	431
13	165	200	200	4.5	116	334
14	165	200	200[3]	4.5	100	331
15	165	200	200[3]	6.0	106	374
16	82	100	50	6.0	121	389
17	0	0	0	6.0	112	396

[1] Least significant difference needed for comparison at:

5-percent point	16	80
1-percent point	22	106

[2] Normal soil pH 4.5; soil raised to pH 6.0 with 7,500 pounds of $CaCO_3$ per acre.

[3] Plus 20 tons of cachaza, filter-press cake, averaging about 1 percent each of N, P, and K on a dry-weight basis.

gave significantly higher yields than those where the fertilizer was used alone (table 2, compare treatment 14 with 13 and 15 with 7).

Capó *et al.* (5) reported no response to filter-press cake when used with fertilizers for sweetpotatoes grown on Fajardo clay at Río Piedras.

The application of liquid fertilizer (a commercial preparation of an 8–10–5) at rate equal to the cost of 1,000 pounds of a commerical 8–10–5[3]

[3] Equivalent to a 10–10–5 formula with the nitrogen expressed as NH_3 which was used in Puerto Rico prior to 1951.

in solid form showed, that on an equal-cost basis, the commercial 8–10–5 solid fertilizer gave significantly higher yields in the Sabana Seca experiment (table 1, treatments 11 and 12). In the Loiza I experiment, the difference was not significant.

TABLE 7.—*Influence of minor-element fertilizers on the starch and carotene content of sweetpotatoes: Loiza experiments on Cataño Loamy Sand*[1]

No.	Treatment[2]		Loiza experiment I				Loiza experiment II			
	Element	Form applied	Rate of application per acre	Starch content (Dry weight)	Carotene content		Rate of application per acre	Starch content (Dry weight)	Carotene content	
					Fresh weight	Dry weight			Fresh weight	Dry weight
			Pounds	*Percent*	*Mcg./gm.*	*Mcg./gm.*	*Pounds*	*Percent*	*Mcg./gm.*	*Mcg./gm.*
1	None	—	—	57	105	338	—	56	127	441
2	Boron	Borax	30	52	101	326	50	56	127	476
3	Magnesium	Magnesium oxide	50	59	102	318	200	62	127	437
4	Copper	Copper sulfate	25	55	97	302	—	—	—	—
5	Manganese	Manganese sulfate	25	53	95	282	—	—	—	—
6	Calcium	Calcium sulfate	—	—	—	—	—	—	—	—
7	Boron Magnesium	Borax Magnesium oxide	—	—	—	—	50 200	62	124	448

[1] Least significant difference needed for comparison at:

5-percent point	8	23	75	29	13	55
1-percent point	10	31	99	40	19	76

[2] All treatments received 165 pounds each of N and 200 pounds each of P_2O_5 and K_2O per acre.

Influence of Lime and Minor-Element Fertilizers on Yields

Calcium

The yields of sweetpotatoes were measurably affected by the use of calcium carbonate in the acid Lares clay (table 4). The application of ground limestone (96 percent $CaCO_3$) to raise the soil pH gave increased yields with increased soil pH. From pH 4.5 to pH 7.0, the yields of sweetpotatoes increased significantly; the increase in yield was 50.2 percent from a soil pH of 4.5 to one of 7.0 (table 4, compare treatments 4 and 1).

The effect of lime on yield increases was also evident where varying levels of nitrogen were used (table 2, treatments 1, 2, and 11, 12); an aver-

age yield increase of 44.5 percent was realized with the use of lime at the various nitrogen levels. The yields of sweetpotatoes were significantly increased when lime was used with filter-press cake (table 2, compare treatments 14 and 15).

The Sabana Seca experiment gave yield increases from the use of calcium sulfate (gypsum) at the rate of 500 pounds per acre (table 3, treatments 1 and 6).

TABLE 8.—*Influence of minor-element fertilizers on the starch and carotene content of sweetpotatoes: Sabana Seca experiment on Sabana Seca Sandy Clay*[1]

No.	Treatment[2]		Sabana Seca experiment			
	Element	Form applied	Rate of application per acre	Starch content (dry weight)	Carotene content	
					Fresh weight	Dry weight
			Pounds	*Percent*	*Mcg./gm.*	*Mcg./gm.*
1	None	—	—	64	125	379
2	Boron	Borax	30	67	116	351
3	Magnesium	Magnesium oxide	100	59	134	405
4	Copper	Copper sulfate	—	—	—	—
5	Manganese	Manganese sulfate	25	63	121	362
6	Calcium	Calcium sulfate	500	62	135	412
7	Boron Magnesium	Borax Magnesium oxide	—	—	—	—

[1] Least significant difference needed for comparison at:

5-percent point	7	15	51
1-percent point	9	20	67

[2] All treatments received 165 pounds each of N and 200 pounds each of P_2O_5 and K_2O per acre.

Magnesium

The results of the magnesium treatments were not consistent. Magnesium gave a significant yield increase at the 1-percent level when 300 pounds of MgO were used in conjunction with lime, but gave no increase when used in conjunction with both lime and boron (table 4, compare treatment 3 with 6 and 9 with 10). Significant increases, however, were not realized from the use of 600 pounds of MgO. (Table 4, treatments 3 and 7.) No yield increases were obtained from the use of MgO in the Loiza and Sabana Seca experiments (table 3).

Boron

The use of boron gave significant yield increases in the Sabana Seca and Corozal experiments. The use of 30 pounds of borax in the Sabana Seca

experiment gave an increase of 16 percent (table 3, treatments 1 and 2). The Corozal experiment showed an almost significant increase in yield when 50 pounds of borax were used in conjunction with lime (table 4, compare treatments 3 and 9). Borax alone gave no significant yield response (table 4, compare treatments 1 and 8). With both magnesium and borax, no significant yield increases were obtained in the acid Lares clay until

TABLE 9.—*Influence of minor-element fertilizers on the carotene content of sweetpotatoes: Corozal experiment on Lares Clay*[1]

No.	Treatment[2]			Soil pH[3]	Carotene	
	Element	Form applied	Rate of application per acre		Fresh weight	Dry weight
			Pounds		*Mcg./gm.*	*Mcg./gm.*
1	None	—	—	4.5	116	334
2	Calcium	Calcium carbonate	3,500	5.0	129	432
3	do.	do.	7,500	6.0	124	409
4	do.	do.	12,500	7.0	132	438
5	Magnesium	Magnesium oxide	300	4.5	97	311
6	Magnesium	Magnesium oxide	300	6.0	123	388
	Calcium	Calcium carbonate	7,500			
7	Magnesium	Magnesium oxide	600	6.0	123	406
	Calcium	Calcium carbonate	7,500			
8	Boron	Borax	50	4.5	126	413
9	Boron	Borax	50	6.0	129	449
	Calcium	Calcium carbonate	7,500			
10	Boron	Borax	50	6.0	124	432
	Magnesium	Magnesium oxide	300			
	Calcium	Calcium carbonate	7,500			

[1] Least significant difference needed for comparison at:

5-percent point	16	80
1-percent point	22	106

[2] All treatments received 165 pounds each of N and 200 pounds each of P_2O_5 and K_2O per acre.

[3] Normal soil pH 4.5; soil raised pH 5.0 with 3,500 pounds $CaCO_3$; pH 6.0 with 7,500 pounds $CaCO_3$; and pH 7.0 with 12,500 pounds of $CaCO_3$ per acre.

lime was added. It appears that in this soil, the major limiting factor for yield in sweetpotatoes is the low pH which may be corrected by liming.

Manganese and Copper

No yield increases were realized with the use of manganese or copper for sweetpotatoes in the Loiza experiment and manganese in the Sabana Seca experiment (table 3, treatments 1, 4, and 5).

Influence of Major-Element Fertilizers on Carotene and Starch Content

Nitrogen

The use of nitrogen fertilizers influenced the carotene content of the sweetpotatoes. In all four experiments, where nitrogen produced yield increases, there were also increases in the carotene content of the sweetpotatoes. When no significant yield increases were obtained with the use of nitrogen, there were no significant variations in the carotene content. Significant decreases in yield from the use of nitrogen were not accompanied by any significant change in carotene content.

The use of nitrogen fertilizers on nitrogen-deficient soils at rates (82 pounds N per acre) which produced significant yield increases, also increased the carotene content of the sweetpotatoes. This was statistically significant in the Sabana Seca experiment (table 5, treatments 1 and 2). Reductions in yields were obtained with the use of 165 pounds of N per acre in the Loiza and Sabana Seca experiments, without measurable change in the carotene content (table 5, compare treatments 2 and 7). In the Corozal experiment (table 6), significant yield reductions were obtained with increasing nitrogen applications on the limed and unlimed soil, and the carotene content showed no significant variation.

Nitrogen had no significant influence on starch content.

Phosphorus

There was an increase of the carotene content of the sweetpotato when accompanied by a significant increase in yields from phosphorus applications. In the Corozal experiment, the use of 300 pounds of P_2O_5 gave a significant increase in yield and carotene content (table 6, compare treatments 3 and 8). In the other experiments, no increases were obtained in yield or carotene content with phosphorus applications.

There was no significant influence of phosphorus on the starch content of the sweetpotatoes.

Potassium

No significant effect on the carotene content was noted for potassium, except for a decrease in carotene in the Loiza experiment (table 5, compare treatments 5 and 6). Ijdo (8) found that decreases of the carotene content of spinach by additions of potassium was only effective at low nitrogen levels. At high nitrogen levels, potassium had no influence on the carotene content. This may have been because all potassium treatments in the sweetpotato experiments were conducted at high nitrogen levels (165 pounds N per acre).

Potassium had no significant influence on the starch content of sweetpotatoes.

Influence of Lime and Minor-Element Fertilizers on Carotene and Starch Content

Calcium

The carotene content of the sweetpotatoes was measurably affected by the use of calcium carbonate in the acid Lares clay (table 9). The application of ground limestone (96 percent $CaCO_3$) to raise the soil pH produced an increase in the carotene content of the sweetpotatoes with the increased soil pH. From pH 4.5 to pH 7.0, the carotene content increased significantly 14 percent on a fresh-weight and 31 on a dry-weight basis.

When lime was used in combination with magnesium oxide (table 9, treatment 6), the carotene content increased over that for the treatment with magnesium oxide (table 9, treatment 5). A similar increase was not obtained when lime was used in combination with boron (table 9, treatment 9 minus treatment 8).

Significant increases were obtained in sweetpotato yields with the use of lime on the acid Lares clay (table 4) and with calcium sulfate (gypsum) in the Sabana Seca experiment (table 3). In most cases where the use of calcium gave significant yield increases, the carotene content increased appreciably.

Calcium had no significant influence on the starch content of the sweetpotatoes.

Magnesium

The carotene content of the sweetpotato was not influenced by applications of magnesium, nor were the yields affected. Ellis and Hamner (7) obtained no measurable effect on the carotene content of tomatoes grown in sand culture with wide variations in the supply of magnesium; Bernstein, Hamner, and Parks (3) noted no appreciable effect of magnesium on turnips grown in soils, but they did obtain a decrease in carotene content with deficient supplies of magnesium in sand culture.

Magnesium had no significant influence on the starch content of sweetpotatoes.

Boron

The use of boron produced no significant increases in the carotene content of the sweetpotato in the Corozal experiment at the original soil pH 4.5, or when lime was added to raise the pH to 6.0 (table 9, treatments 8 and 9). The Sabana Seca experiment exhibited significant yield increases due to boron without any effect on the carotene content (table 8). The Loiza experiments gave no significant differences in yield or carotene content attributable to boron.

Boron had no significant effect on the starch content of the sweetpotatoes.

Manganese and Copper

There were no indications that either manganese or copper significantly influenced the carotene content or yield of sweetpotatoes in the experiment on Cataño loamy sand (table 7).

DISCUSSION

The use of lime produced highly significant yield increases for sweetpotatoes in acid soils only (lower than pH 6). The addition of lime to the acid Lares clay made possible yields greater than those obtained with high rates of fertilizer applications without any lime. Even on the Sabana Seca sandy clay at pH 6.4, the use of a gypsum ($CaSO_4 \cdot 2H_2O$) gave significant yield increases. Calcium is essential for proper root development. The results of these experiments indicate that the use of lime on acid soils is of primary importance for obtaining high yields of sweetpotatoes in Puerto Rico. No fertilizer program should be undertaken for sweetpotatoes without due consideration for proper liming of the soil.

The correct balance of fertilizer nutrients is important for sweetpotatoes. The presence of excessive amounts of nitrogen produces lower yields. In the four experiments performed on three distinct soil textures, the application of 82 pounds of nitrogen was the maximum needed. In the Corozal experiment, there was sufficient soil nitrogen present to render the use of the 82 pounds of nitrogen excessive.

The yield increases attributable to potash applications were not consistent. In general, potash additions increased yields. Phosphorus applications generally produced no yield responses. In view of these results the recommendation of a 8–6–16 fertilizer at a rate of 600 pounds per acre is made for sweetpotatoes, instead of from 600–1,000 pounds of a 10–10–5 now in use.

It is of interest to note that the yields obtained in the four experiments compared favorably to those obtained in the United States. For the Cataño loamy sand, the highest yields obtained were 236 bushels[4] per acre of U.S. No. 1, No. 2, and Jumbo roots, 216 bushels per acre for Sabana Seca sandy clay loam, and 252 bushels per acre for Lares clay. The mean yields of sweetpotatoes per acre for the leading producing states of Louisiana and North Carolina are 115 and 95 bushels, respectively (1). Allowing for a cost of production per acre of sweetpotatoes of $100, a profit of over $150 per acre[5] could be realized with yields averaging that obtained in

[4] One bushel equals 55 pounds of sweetpotatoes.

[5] Calculated with sweetpotatoes selling at $2.50 per hundredweight.

the four experiments. With the proper utilization of variety, plant material, fertilizer, and agronomic practices, Puerto Rico is capable of producing ample yields of sweetpotatoes at a profit to the farmer.

The yields were influenced by time of planting. The Loiza I experiment produced higher yields than the Loiza II experiment. The longer days of the Loiza II experiment (March to July) with greater periods of sunlight gave lower yields than those obtained in the Loiza I experiment with its shorter winter days (October to February). Edmon *et al.* (6) reported similar results in yields attributable to planting dates. The carotene content was higher for the Loiza II experiment planted in the spring than the Loiza I experiment planted in the fall. Ellis and Hamner (7) obtained higher carotene content in tomatoes grown outdoors in summer than in those grown in the greenhouse in the winter.

SUMMARY

The effects of major and minor fertilizer elements on yield and carotene and starch content of sweetpotatoes were investigated, and the following conclusions were drawn:

1. Excessive quantities of nitrogen decreased sweetpotato yields. The use of 82 pounds of N per acre was the highest rate needed in the four experiments.

2. The use of phosphorus fertilizers with rates of applications as high as 200 pounds of P_2O_5 per acre had no effect on yields. With the use of 300 pounds P_2O_5 per acre, a yield increase was obtained only on the Lares clay at Corozal.

3. No consistent increases in yields were obtained with increasing potassium additions to the soil. There was a yield response to the potassium applications on the Cataño loamy sand of the Loiza I experiment. There was no significant response to potassium on Lares clay at Corozal, on Cataño loamy sand at the Loiza II experiment, or on the Sabana Seca sandy clay loam at Sabana Seca.

4. The yields of marketable sweetpotatoes were increased by the use of potassium on Cataño loamy sand at the Loiza I experiment.

5. Filter-press cake used alone gave low yields on Cataño loamy sand. The use of filter-press cake plus fertilizer gave good results both on the heavy Lares clay and on the Cataño loamy sand.

6. The yields of sweetpotatoes were measurably affected by the use of lime in the acid Lares clay. The application of lime to raise the pH gave increased yields with increased soil pH. The Sabana Seca experiment showed yield increases from the use of calcium sulfate (gypsum).

7. No consistent yield increases were obtained from the use of magnesium oxide.

8. The use of boron gave significant yield increases in the Sabana Seca and Corozal experiments, but not in the Loiza experiment.

9. No yield increases occurred with the use of manganese and copper.

10. There was no effect on starch content attributable to any major- or minor-element treatment.

11. The use of nitrogenous fertilizers influenced the carotene content of the sweetpotatoes; where nitrogen applications produced yield increases there were also increases in the carotene content.

12. Increases in carotene content were obtained with phosphorus only when the yields were significantly increased by addition of phosphorus.

13. No significant effect on carotene content was noted for potassium, except for a decrease in one experiment on a Cataño loamy sand.

14. The carotene content of sweetpotatoes was measurably affected by the use of calcium carbonate on acid soils (pH 4.5). Increases in pH were accompanied by increases in carotene content. In most cases where yields were increased by liming, the carotene content increased appreciably.

15. No responses were obtained from the use of boron, magnesium, copper, and manganese on the carotene content of sweetpotatoes. No effects were obtained on yields by use of these elements, except boron on a Sabana Seca sandy clay.

16. A recommendation is made for sweetpotatoes of 600 pounds of a 8–6–16 formula per acre.

17. The yields of sweetpotatoes compared favorably with yields for the leading sweetpotato-producing States of Louisiana and North Carolina.

18. Yields were increased by planting in the shorter days of winter as compared to the longer summer days. Carotene content, however, was increased with spring as compared to winter plantings.

RESUMEN

La investigación llevada a cabo con relación a los efectos de los elementos nutritivos, mayores y menores, que se encuentran en los abonos, sobre el rendimiento, y contenido de carotina y almidón de la batata, dió motivo para llegar a las conclusiones siguientes:

1. Las cantidades excesivas de nitrógeno aplicadas aminoró los rendimientos de la batata. Ochenta y dos libras por acre fué la proporción de nitrógeno más alta necesaria en los 4 experimentos.

2. El uso del fósforo, a razón de 200 libras de P_2O_5 por acre, no tuvo efecto sobre los rendimientos. Cuando se usaron 300 libras de P_2O_5 por acre en un suelo Lares arcilloso, se notó aumento en la producción del experimento en Corozal.

3. No se consiguió aumento consistente en los rendimientos, cuando se aumentó progresivamente la potasa. Hubo aumento en el rendimiento con

las aplicaciones de potasa en los suelos lómicoarenosos del primer experimento en Loíza. Sin embargo, no resultó así en la arcilla Lares en Corozal, en la lómicoarenosa Cataño en el segundo experimento en Loíza, ni en el suelo arenoarcilloso lómico Sabana Seca.

4. Se obtuvo un aumento en los rendimientos de batatas propias para el mercado con el uso de las aplicaciones de potasa en el primer experimento en Loíza.

5. Los rendimientos fueron bajos cuando se usó la cachaza sola en el suelo lómicoarenoso Cataño.

6. Se afectaron marcadamente los rendimientos cuando se usó la cal en los suelos Lares arcillosos. La aplicación de la cal para subir el pH aumentó los rendimientos a la vez. En el experimento en Sabana Seca se registraron aumentos en el rendimiento con el uso del sulfato de calcio (yeso).

7. No se obtuvo aumento consistente alguno por medio de las aplicaciones de óxido de magnesio.

8. Con el uso del boro, hubo aumentos significativos en los rendimientos de los experimentos en Sabana Seca y Corozal, pero no así en el experimento en Loíza.

9. No ocurrieron aumentos en los rendimientos cuando se usaron el manganeso y el cobre.

10. No hubo efecto alguno en el contenido de almidón que pudiera atribuirse a los tratamientos con elementos nutritivos mayores o menores.

11. El uso de los abonos nitrogenados influyó sobre el contenido de carotina en la batata. Cuando se registraron aumentos en los rendimientos, tribuibles al nitrógeno, también aumentó el contenido de carotina.

12. Se obtuvieron aumentos en el contenido de carotina atribuibles al fósforo en todos los casos en que los rendimientos aumentaron debido al uso de este elemento.

13. No hubo efecto significativo en el contenido de carotina cuando se aplicó potasa, excepto en un caso de disminución de la producción en un suelo Cataño lómicoarenoso.

14. El contenido de carotina se afectó marcadamento cuando se usó el carbonato de calcio en suelos ácidos (pH 4.5). Los incrementos en el pH fueron acompañados por los aumentos en el contenido de carotina. En muchos casos, cuando se aumentaron los rendimientos por medio de la cal el contenido de carotina también aumentó marcadamente.

15. El contenido de carotina aparentemente no se afectó cuando las aplicaciones de abono contenían boro, magnesio, cobre, o manganeso, Tampoco estos elementos tuvieron influencia alguna sobre los rendimientos, con excepción del boro en la arcilla arenosa Sabana Seca.

16. Se recomienda, para la batata, un abono con el análisis 8-6-16, a razón de 600 libras por acre.

17. Los rendimientos de la batata, en estos experimentos, comparó

favorablemente con los promedios de producción que se obtienen en los principales estados productores de batata, como lo son Louisiana y Carolina del Norte.

18. Los rendimientos fueron mayores cuando se sembró la batata durante los días cortos del invierno al compararse con la producción de las siembras hechas durante los días largos del verano. Sin embargo, se notó que el contenido de carotina fué mayor en la batata sembrada durante la primavera.

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NEW LEAFHOPPERS FROM PUERTO RICO
(CICADELLIDAE: HOMOPTERA)

JOHN S. CALDWELL[1] AND LUIS F. MARTORELL[2]

Dikraneura althaearoseae n. sp.

Length, 2.6 mm.–3 mm. Specimens in preserving fluid; appearing yellow over all with first and last apical cells of fore wing slightly fumate.

Vertex rather obtuse, blunt. Forewing with second apical cell triangular but not stalked. Style furcate apically; inner apex extended more than outer. Pygofer rather extended dorsoposteriorly on either lateral margin; process small, carved dorsally. Aedeagus with elongate, slender posterior process forked apically; anterior portion somewhat "S"-shaped in lateral aspect. (Fig. 1, A, B.)

Male holotype, female allotype, and paratypes from "varilla de San José," *Althaea rosea*, Río Piedras, March 8, 1951, causing heavy chlorosis on leaves and breeding abundantly. (Martorell)

Protalebra alliodorae n. sp.

Length, male 2.75 mm. female usually slightly longer. Specimens in preserving fluid; appearing yellow with a large, jet-black spot on either forewing at the inner basal angle and posteriorly on the scutellum. A broad smoky band present subapically on the forewings.

Vertex rather acute, almost as broad as pronotum. Pronotum slightly less than twice length of vertex.

Plates elongate, slender, acute apically. Pygofer with slender, posterior projecting process on either dorsoposterior margin. Aedeagus with long, slender base; terminal portion somewhat crescent-shaped with a process arising from the inner apical margin and projecting caudad. (Fig. 2, A, C.)

Male holotype, female allotype, and paratypes from "capa prieto," *Cordia alliodora*, Río Piedras, June 28, 1951; paratypes same data June 29, 1951. (Julio Bird)

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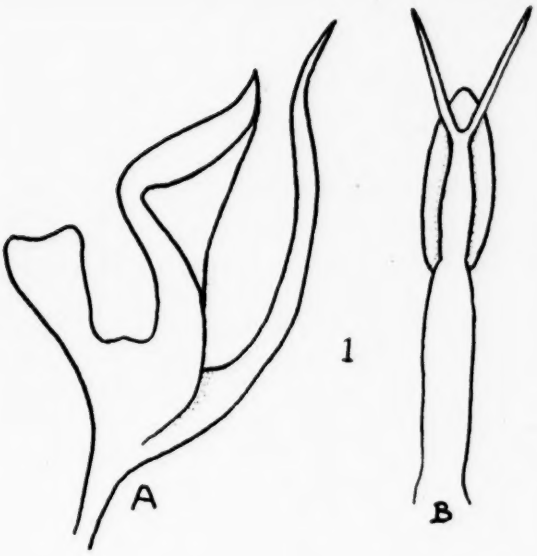

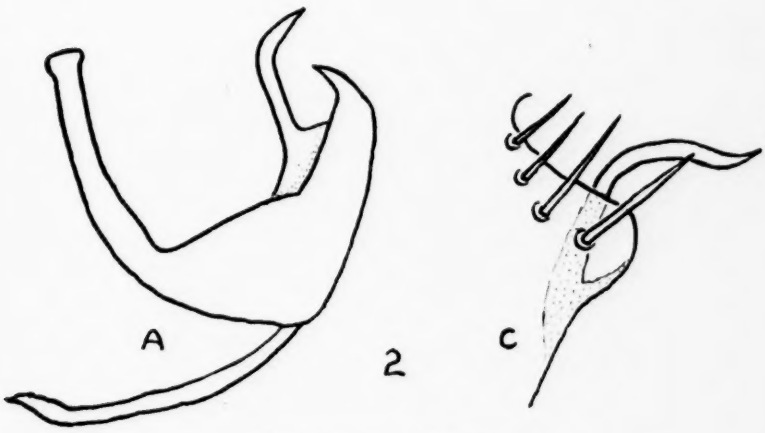

EXPLANATION OF FIGURES

FIGS. 1 and 2: A, Left lateral aspect of aedeagus. B, Posterior aspect of aedeagus. C, Left lateral aspect of pygofer.